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The Plutonium Transition from Nuclear Weapons to Crypt

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THE PLUTONIUM TRANSITION FROM NUCLEAR WEAPONS TO CRYPT

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ABSTRACT

With the end of the "Cold War'" thousands of nuclear warheads are being dismantled. The National Academy of Sciences termed this growing stockpile of plutonium and highly enriched uranium "a clear and present danger" to international security. DOE/MD selected a duel approach to plutonium disposition — burning MOX fuel in existing reactors and immobilization in a ceramic matrix surrounded by HLW glass. MOX material will be pits and clean metal. The challenges come with materials that will be transferred to Immobilization—these range from engineered materials to residues containing < 30% Pu. Impurity knowledge range from guesses to actual data. During packaging, sites will flag "out of the ordinary" containers for characterized. If the process history is lost, characterization cost will escalate rapidly. After two step blending and ceramic precursor addition, cold press and sintering will form 0.5-kg ceramic pucks containing ≤50 g Pu. Pucks will be sealed in cans, placed into magazines, then into HLW canisters; these canisters will be filled with HLW glass prior to being transported to the HLW repository. The Immobilization Program must interface with DP, EM, RW, and NN. Overlaid on top of these interfaces are the negotiations with the Russians.

INTRODUCTION

Since its discovery in 1941 and its dramatic emergence at Nagasaki, Pu altered the course of history, changed concepts and consequences of war, and paradoxically has become a powerful instrument for peace (1,2). Approximately 1600 to 1700 tonnes of weapons-usable Pu have been generated worldwide. (3,4)

Between 1944 and 1988, the U. S. built 14 Pu-production reactors (nine at Hanford and five at Savannah River) producing approximately 111.4 tonnes of Pu (2,3,5); 103.4 tonnes of weapons grade Pu(5). With the fall of the Berlin Wall in 1989, signaling the end of the "Cold War", the U. S. stopped production of weapons-grade Pu (5). The National Academy of Sciences report on the "Management and Disposition of Excess Weapons Plutonium" (6) characterized the threat that nuclear weapons or materials could fall into the hands of terrorists or non-nuclear nations through theft or diversion as a "clear and present danger." The danger exists not only in the potential for proliferation of nuclear weapons, but also in the potential for environmental, safety and health consequences if surplus fissile materials are not properly managed. (6,7)

Russia has not disclosed the amount of Pu produced, but various estimates indicate that production was 130 to 170 tonnes. (2, 8, 9) Production has been curtailed in Russia; 3 dual-purpose reactors still produce weapons-grade Pu — two at Tomsk-7 (renamed Seversk) and one at Krasnoyarsk-26 (renamed Zheleznogorsk Mining and Chemical Combine). In a 1994 United States-Russian agreement that has yet to enter into force, Russia agreed to close the remaining operating reactors by the year 2000. (2, 6)

Treaties (10 - 12) between the United States and Russia have already cut the number of nuclear warheads. Publicly available estimates suggest that the U. S. stockpile of intact nuclear weapons stood at approximately 23,500 by the late 1980s and had declined by 1996 to approximately 14,000 to 15,000 weapons. Unless further arms reduction agreements are reached, dismantlements in the United State is reported planned to leave an estimated 10,000 warheads remaining in the stockpile. Under current plans, if START II is ratified the warheads retired as a result reportedly will simply be shifted from active to reserve status, without being eliminated. "…The START II Treaty calls (10, 12) for the United States and Russia to reduce their deployed, strategic forces to 3,000 – 3,500 warheads on each side…"

A similar pattern appears to be prevailing in Russia (9). Unclassified estimates suggest that the Soviet nuclear arsenal, now entirely inherited by Russia, has declined from a peak that may have been as high as 45,000 weapons in 1986 to perhaps 25,000 weapons as of 1996.

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Further progress in arms reduction (9, 10) could substantially increase the amount of excess fissile material.

The U S and the nations of the FSU are therefore engaged in arms reduction on an unprecedented scale (10). For the first time the world is faced with the need to manage tens of tonnes of excess weapons-grade Pu derived from tens of thousands of weapons being dismantled. These are global issues: All states bear a share of the risk, and all states using nuclear energy for military purposes or civilian power production share the responsibility. Disposing of these materials in a manner that is secure, transparent, and makes their reuse in weapons difficult would increase international confidence in U. S. and Russian nuclear arms reductions.

Fissile material is the key ingredient needed to build nuclear weapons, and knowledge of how to use either Pu or HEU to build at least a crude (but still very powerful) nuclear bomb is widespread (13). Keeping these materials out of the hands of other nations and subnational groups is an essential ingredient of nonproliferation and anti-terrorism policies.

President Clinton (1, 3, 7) announced, on September 27, 1993, the establishment of a framework for United States' efforts to prevent the proliferation of weapons of mass destruction. Key elements of the President's policy stated that the United States would:

1) Seek to eliminate, where possible, accumulation of stockpiles of Pu,
2) Ensure that these materials are subject to the highest standards of safety, security, and international accountability, and
3) Initiate a comprehensive review of long-term options for Pu disposition, taking into account technical, nonproliferation, environmental, budgetary, and economic considerations.

In response to the President's declaration, the Secretary of Energy and the Congress took action in October 1994 to create a permanent Office of Fissile Materials Disposition (7) within the Department of Energy.

On September 2, 1998, the Presidents (14) of the United States and Russia signed the "Joint Statement of Principles for Management and Disposition of Plutonium Designated as No Longer Required For Defense Purposes." In this joint statement the Presidents "affirm the intention of each country to remove by stages approximately 50 metric tons of plutonium from the nuclear weapons programs, and to convert this material so that it can never be used in nuclear weapons…and…to ensure that these materials do not become a proliferation risk."

The United States (15 – 26) has proposed that it manage it's 50 tonnes by a dual approach—once through MOX burning of a portion of the plutonium and immobilization in a ceramic matrix followed by encasement in high level waste glass. This approach allows for the immobilization of approximately 17 tonnes of surplus plutonium and use of up to 33 tonnes as MOX fuel (21 – 23, 25, 26). The Savannah River Site (SRS) has been selected as the location for all of the disposition facilities. However, construction of new facilities for the disposition of surplus plutonium will not take place unless there is significant progress on plans for plutonium disposition in Russia,

Russia has proposed that it will manage its full 50 tonnes by burning in a reactor. (21 - 23)

In parallel to the problem of excess weapons materials, the world is also currently faced with a growing accumulation of Pu being separated in civilian nuclear power programs.(4, 21, 27) Slightly more than 100 metric tonnes (tonnes) of separated Pu are in civilian stockpiles today, increasing at a rate of 15 tonnes per year. The annual separation rate is about 23 tonnes, compared to a consumption rate of about 8 tonnes per year. Most of the separated Pu is in the UK, France, and Russia, with increasing amounts owned by Japan and Germany.

INTERNATIONAL APPROACHES TO THE EXCESS PLUTONIUM PROBLEM

President Clinton's nonproliferation policy (28) reaffirmed the long-standing position that "the United States does not encourage the civil use of plutonium, and accordingly does not itself engage in plutonium reprocessing for either nuclear power or nuclear explosive purposes." It also stated, however, that the United States "will maintain its existing commitments regarding the use of plutonium in civilian programs in Western Europe and Japan." The nuclear industries in France, UK and Russia have constructed large commercial reprocessing plants for recovery of Pu from spent power-reactor fuel. Recycling of this separated plutonium has begun on a significant scale in Western Europe and preparations for large-scale plutonium reprocessing and recycling are under way in Japan. Russia has thus far stockpiled approximately 35 tonnes of Pu recovered from power-reactor fuel.

The present context (14) for U. S. and Russian decisions about the disposition of their excess weapons Pu is:

1) The United States does not encourage the civil use of plutonium [because] its continued production is not justified on either economic or national security grounds, and its accumulation creates serious proliferation and security dangers."
2) The Russian nuclear establishment sees separated plutonium as a possibly valuable future nuclear fuel from which economic value should be realized; and
3) The West European and Japanese nuclear establishments in general support the use of weapons plutonium in fuel and are offering to cooperate with both the U. S. and Russia in the implementation of such a strategy.

THE UNITED STATES APPROACHES TO THE EXCESS PLUTONIUM PROBLEM

THE MOX APPROACH IN THE U. S.

On March 22, 1999, Duke Engineering Services, COGEMA, Inc. and Stone & Webster, (known as DCS) was awarded a multi-phase contract to design, license, construct, operate, and deactivate the mixed oxide (MOX) fuel fabrication facility and provide irradiation services (25). The irradiation services will be provided in six specific reactors:

a) Catawba Nuclear Station—Units 1 and 2 in South Carolina
b) McGuire Nuclear Station—Units 1 and 2 in North Carolina, and
c) North Anna Power station—Units 1 and 2 in Virginia.

The DCS approach for fabricating MOX fuel (see Figure 1) includes an aqueous processing capability to purify and condition the plutonium oxide feedstock. (26, 28 - 34) The proposed aqueous polishing involves mediated electrochemical [using Ag(II)] dissolution of plutonium oxide, followed by purification of the plutonium via one cycle of solvent extraction, oxalate precipitation, and calcination to the oxide. This polishing scheme would not only remove the gallium and ingrown americium but would provide the correct morphology for preparation of the MOX fuel.

The start-up feed for the MOX fuel fabrication facility (MOX FFF) is anticipated to be about 1,200 kg of high purity plutonium oxide. Once the start-up phase for the MOX FFF is over, it is assumed that the Pit Dismantlements and Conversion (PD&C) facility will be operational. The PD&C should then provide 25 tonnes of plutonium oxide derived from weapons dismantlements and clean plutonium metal. If additional metal pits are withdrawn from the stockpile (START 3), the assumed 7 tonnes of additional metal would be dispositioned via the MOX route, yielding a total of 33 tonnes of plutonium dispositioned via the MOX route.

Figure 1. The MOX Approach

THE IMMOBILIZATION APPROACH IN THE U. S.

The Immobilization Program (2, 3, 16, 24 - 26, 28, 29, 35 - 44) in the United States (see Figure 2) would mineralize the plutonium presently contained in a variety of residues that were left in place when the weapons production complex was shut-down at the end of the Cold War. These residues have a wide range of impurity contents, typically from a few parts per million to > 90 wt. %. Plutonium in these residues would be blended to levelize the impurities and thereby avoid reprocessing of this plutonium. This blended plutonium would then be mineralized by reactive sintering at high temperature in a titanate ceramic followed by canning of the ceramic pucks. Four of these cans would by loaded into a magazine and seven magazines or 28 cans will be loaded into a support structure within an empty HLW canister. The canister will then be filled with borosilicate glass containing high level waste in the Defense Waste Processing Facility (DWPF) at SRS. This extremely durable and tamper resistant form is designed to meet U. S. non-proliferation goals and will be safe for geologic disposal.

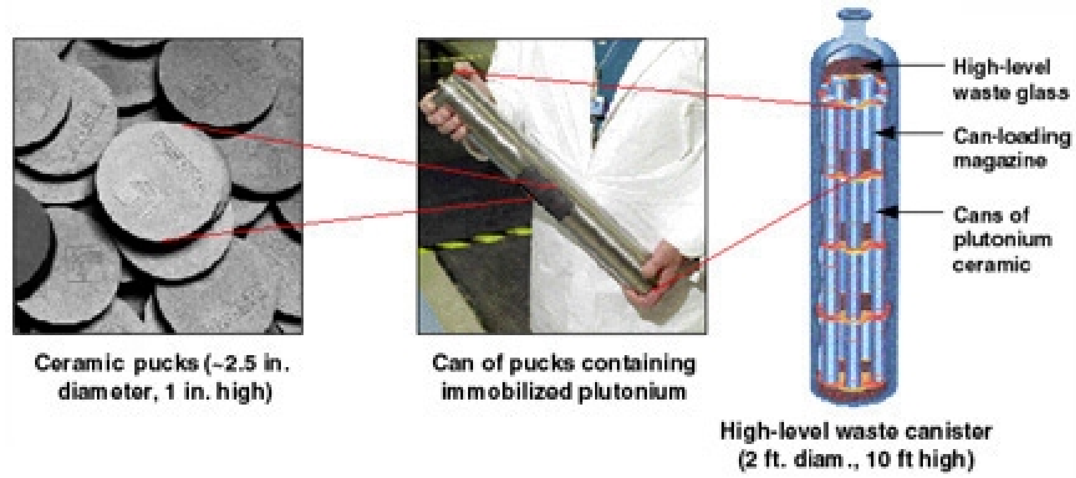

Figure 2. Ceramic can-in-canister concept

The can-in-canister approach must satisfy several requirements. First, it must meet the repository qualifications for a waste form. The repository requirements include achieving low leach rates and incorporation of neutron poison elements to preclude criticality. Second, immobilization must meet the spent fuel standard (3, 45, 46) for nonproliferation. Third, the process must be flexible, capable of handling a variety of impurities and a total quantity of plutonium varying from about 12 MT to 50 MT during a 10-year campaign

PROCESS FLOWSHEET

The immobilization process flow is illustrated in Fig. 3. The overall process can be divided into four major systems:

a) material receipt and storage;
b) plutonium materials conversion into acceptable oxide feed;
c) first stage immobilization involving ceramic formation and can loading; and
d) second stage immobilization involving the can-in-canister operations in the PIP and in the DWPF.

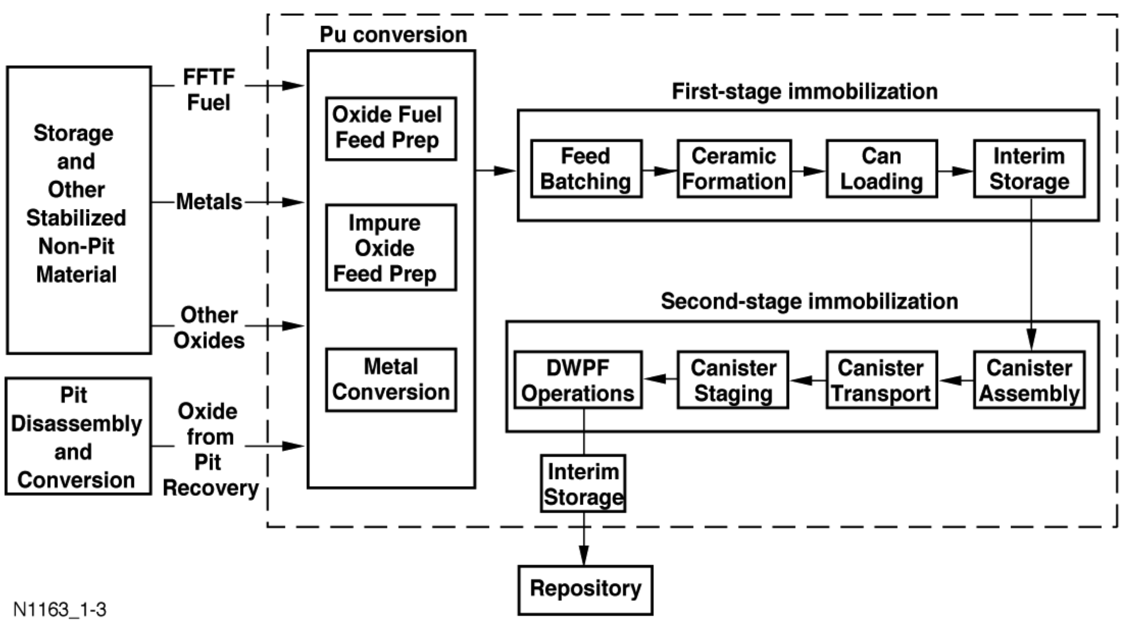

Figure 3. Process flow diagram

The metal conversion process converts plutonium metal and alloys to a stable oxide using a dry gaseous process with minimal secondary wastes. This process includes the following steps: hydride/nitride reaction, transfer of plutonium nitride to a separate fluidized bed oxidation furnace, and oxidation.

Blending will be used to minimize other processing and characterization costs and to improve product quality and reproducibility of the immobilized form.

The first stage of immobilization will convert plutonium oxide (along with its accompanying uranium oxide and tramp impurity oxides) to a monolithic, multiphase, crystalline ceramic, predominantly the mineral pyrochlore. The product form will also contain varying amounts of zirconolite, brannerite, and rutile as well as potentially other phases. The ceramic immobilized plutonium will be sealed into cans.

The second stage of immobilization will encapsulate canned ceramic forms in high-level waste (HLW) glass containing ^{137}Cs at the Defense Waste Processing Facility (DWPF). The HLW glass will provide the radiation barrier required to meet the "spent fuel standard."

DISPOSITION FEEDSTOCKS

EXCESS PLUTONIUM FROM A DOE CORPORATE VIEWPOINT

From 1944 to September 1994, the U. S. Government produced and acquired a total of 111.4 tonnes (5) of plutonium. During the same period of time, 12.0 tonnes of plutonium were removed resulting in an actual inventory of 99.5 tonnes as of September 30, 1994 (see Figure 1). Removals include that expended in wartime and tests (3.4 tonnes), normal operating losses. (3.4 tonnes), fission and transmutation (1.2 tonnes) inventory differences (2.8 tonnes), foreign countries (0.7 tonnes), civilian industry (0.1 tonnes), decay and other removals (0.4 tonne].

DOE categorizes ^{239}Pu as either weapons grade, fuel grade or reactor grade, depending upon the amount of ^{240}Pu and ^{241}Pu it contains (5):

a) Weapons grade plutonium contains less than 7% ^{240}Pu.
b) Fuel grade plutonium contains from 7% to less than 19% ^{240}Pu and
c) Power reactor grade contains from 19% and greater ^{240}Pu.

The U. S. plutonium inventory is composed of 85.0 tonnes of weapon grade, 13.2 tonnes of fuel grade, and 1.3 tonnes of reactor grade.

With the end of the Cold War and the associated cuts in the superpower nuclear arsenals, the U. S. and Russia must together dispose of tens of tons of excess weapons plutonium and hundreds of tons of excess weapons uranium. On September 27, 1993, the President issued a Nonproliferation and Export Control Policy (7), which set forth the framework for U. S. efforts to prevent the proliferation of weapons of mass destruction. As a key element of the presidents policy, the U. S. committed to eliminating, where possible, the accumulation of highly enriched uranium and plutonium and to ensure that where these materials already exist, they are subject to the highest standards of safety, security, and international accountability. In support of this policy, the Departments of Energy and Defense performed an in-depth review of the fissile material required to support the nuclear weapons program and other national security needs (47). This was compared to available materials and as a result 38.2 tonnes of weapon grade plutonium (5, 47, 48) was declared excess to the amount needed for national defense (see Table 1).

Table 1. Excess weapons grade Plutonium (Tonnes Pu)

Location	Metals	Oxides	Reactor Fuel	Irradiated Fuel	Other forms	Total
Pantex/future dismantlements	21.3					21.3
Rocky Flats	5.7	1.5			4.6	11.9
Hanford Site	<0.1	1.0		0.2	0.5	1.5
Los Alamos	0.5	<0.1	<0.1		1.0	1.5
Savannah River	0.4	0.5		0.2	0.2	1.3

INEL	<0.1		<0.2	0.2	<0.1	0.4
Other Sites	<0.1			<0.1	<0.1	0.1
Total	27.8	3.1	0.2	0.6	6.4	38.2

Note: Totals may not add up due to rounding to the nearest tenth of a tonne

In February 1994, then-Under Secretary Charles B. Curtis (46) launched the Materials in Inventory (MIN) Initiative. For the purposes of the MIN Initiative, the Department defined "materials in inventory" as materials that:

a) Are not currently in use,
b) Have not been designated as waste, and
c) The Nuclear Weapons Council, a panel consisting of high-level executives from the Departments of Energy and Defense and the National Security Council, has not set aside for national defense purposes. For this Initiative,

The Department currently manages approximately 52.6 metric tons of plutonium not in weapons (47):

- Approximately 73 percent (38.2 tonnes) of the 52.6 metric tons reported is weapons grade plutonium. Most of this material (27.8 metric tons) is in metal form; the remaining 10.4 metric tons comprise oxides, spent nuclear fuel, unirradiated fuel, and other forms.
- Approximately 27% [14.2 tonnes] of DOE's plutonium inventory is reactor or fuel grade. Plutonium contained in spent fuel accounts for the largest portion of this material, representing 6.9 tonnes; the remaining 7.5 tonnes comprises all other forms.

EXCESS PLUTONIUM FROM A MD VIEWPOINT

April 1997 the Office of Materials Disposition published (48) its feed materials planning bases for the announced 50 tonnes of plutonium (See Table 2). Note that to obtain the 50 tonnes of plutonium promised by the President, MD has to assume the 38.2 tonnes of weapons grade declared excess, all of the non-weapon grade plutonium in the DOE inventory, and 7 tonnes from future weapons dismantlements. Note that there were also the assumptions that:

a) 2 tonnes of weapons grade plutonium was unsuitable for weapons use and would be discarded to WIPP,
b) an additional 0.6 tonne of weapon grade plutonium was still in irradiated targets and would be disposed of as spent fuel in the national repository, and
c) 6.9 tonnes of non-weapons grade plutonium remains in unprocessed reactor fuel and would be disposed of as spent fuel in the national repository.

Table 2. Surplus Pu feed Materials Planning Bases (48)

Category	Weapons-Grade Pu	Non-Weapons-Grade Pu	Total Surplus Pu
Metal	**27.9**	**1.0**	**28.9**
Oxide	**3.1**	**1.3**	**4.4**
Reactor Fuel	**0.2**	**4.4**	**4.6**
Irradiated Fuel	**0.6**	**6.9**	**7.5**
Other forms	**6.4**	**0.7**	**7.1**
Total Surplus Pu	**38.2**	**14.3**	**52.5**
Assumed non-weapons-usable	**2.6**		**9.5**
Assumed weapons-Usable	**35.6**	**7.4**	**43.0**
Pu assumed declared surplus in future	**7.0**		**7.0**
Weapons-Usable Pu Post-Stabilization	**42.6**	**7.4**	**50.0**

Note: Totals may not add up due to rounding to the nearest tenth of a tonne

MD Objectives. MD has only one surplus ^{239}Pu objective: “Achieve national non-proliferation objectives by converting surplus plutonium into forms meeting the spent fuel standard.”

PLUTONIUM ACCEPTANCE SPECIFICATIONS

Along with the assumption that the DOE Corporate Viewpoint would prevail as to the feed stock coming into the disposition program, the following set of assumptions was also made. The complete set of assumptions allowed the program to arrive at a set of acceptance specifications that are user friendly but still allows reasonable control of the ceramic product produced in the Pu immobilization plant (36, 49). These assumptions were:

A. Separated Pu that is declared excess will either be disposed of in accordance with the spent fuel standard at the Federal Repository or will be diluted below the safeguards termination limit and disposed at WIPP. Fuels irradiated by DOE will be dispositioned at the Federal Repository by EM as part of the spent fuel program.
B. The MD immobilization facility will begin operations in the 2005 to 2006 time frame. It is assumed that this facility will be at the SRS.
C. The head-end of the Pu immobilization facilities will have the capability to:
   1) Convert metals to oxide
   2) Dejacket unirradiated fuel elements
   3) Grind materials
   4) Calcine materials
   5) Leach soluble salts from materials
D. Blending will be used to minimize other processing and characterization costs and to improve product quality and reproducibility of the immobilized form.
E. The Pu Immobilization Facility will operate as an unclassified facility with International Atomic Energy Agency (IAEA) or other international inspections anticipated. Therefore, no classified materials will be accepted at the immobilization facility.
F. All Pu declared excess (materials neither part of the strategic reserve nor previously scheduled to be transferred to WIPP) would be available to the immobilization facility on demand.

GENERAL CHARACTERIZATION OF THE FEED STOCK (36, 39, 44)

The isotopic composition of the 50 tonnes of excess Pu varies from about 3% ^{240}Pu to approximately 40% ^{240}Pu. The Pu assay varies from more than 10-wt% to less than 99-wt%. The last date of purification of these materials varies from the early 1960s to the late 1990s; therefore, the ^{241}Am content varies from as little as 200-ppm to as much as 15-wt%. The uranium content varies from trace depleted uranium in the Pu to trace Pu in fully enriched uranium (93% ^{235}U). In general, the impurities in the existing feed stock are dominated by the following elements: aluminum, carbon, calcium, chlorine, chromium, iron, fluorine, gallium, potassium, magnesium, molybdenum, sodium, silicon, tantalum, uranium, tungsten, and zinc. It is obvious that large-scale blending will be necessary to obtain reasonably consistent Pu feed stream.

BLENDING STRATEGY

The blending strategy (36, 39, 44) is similar to the traditional metal blending strategy used to manufacture nuclear weapons. Using this strategy, metal was divided into four grades depending upon the level of impurities: categories I, II, and III, and war reserve metal. The war reserve grade met the impurity specifications for the metal to be used in weapons. Category I metal was higher purity material than required to meet war reserve specifications. Category II metal had impurities that could easily be blended with Category I to give war reserve metal. This allowed a larger fraction of the available metal to proceed to the weapons foundry than would have otherwise been possible. Category III generally meant that impurities were too great to allow blending to war reserve specifications without careful planning of the blend mixture. The rule of thumb was “always ask Rocky Flats to consider the blending route first before you considered repurification.”

Chemical data for the excess feedstock vary in completeness but approximations are as follows:

A. Group I Materials. Materials with purity far exceeding what is required for immobilization: approximately 45 tonnes of the 50 tonne case, or approximately 13 tonnes for the 18 tonne case.
B. Group IIa Materials. Materials with impurities that can be blended into acceptable feed stocks for immobilization: approximately 3 tonnes of Pu.
C. Group IIb Materials. Materials with impurities the Immobilization Conversion Facility can accommodate: approximately 1 tonne of Pu. This includes the “chloride oxides” at Rocky Flats and at Hanford.

D. Group IIIa Materials. Materials previously identified by internal DOE studies as requiring processing in the SRS canyon (aqueous dissolution and reprecipitation): approximately 1 tonne of Pu. These materials include fluoride materials and scrub alloy at Rocky Flats as well as sand, slag, and crucible materials at both Rocky Flats and Hanford. After processing at Savannah River, these materials will move into Group I.
E. Group IIIb Materials. Salt residues from molten salt processing. These have been previously identified as needing removal of the chloride salts for stabilization purposes: approximately 1 tonne of Pu. After removal of about 75% of the 16 tonnes of spent chloride salts, this material would meet the description of Group IIb.
F. Group IIIc Materials. There is a group of materials that, if calcined to remove carbon, could come to the immobilization program. These materials are under study to determine just how much can be absorbed within the immobilized product. Some of these materials have Pu contents as low as 5 to 10-wt%.

POST-BLENDING SPECIFICATIONS

Just as in nature, the minerals formed during the fabrication of the ceramic Pu immobilization product depend upon the ratio of the individual elements that are present in the feed materials. Also, just as in nature, the minerals can accommodate a fairly wide range of elements so long as substitution is possible. These substitution rules are based upon atomic charge and ion size. The substitution rules (49), which represent specifications for post-blended feed to ceramic fabrication, are given in Table 1.

WHAT HAS HAPPENED TO THE FEEDSTOCK?

EXCESS PLUTONIUM FROM AN EM VIEWPOINT

Growing concerns about safety and environmental problems caused the DOE to suspend temporarily various operations throughout the nuclear weapons complex in the late 1980's and early 1990's. Many of these temporary shutdowns became permanent with the end of the Cold War and the collapse of the Soviet Union in 1991. However, because the shutdowns were viewed as temporary at the time, the DOE did not make long-term storage or disposition plans for surplus materials prior to suspending operations.

The end of the "Cold War" created new challenges for the Nuclear Weapons Complex. The sudden end of weapons material requirements created a profound shift in facility missions; budgets were dramatically reduced. The sudden, complete cessation of processing left tonnes of Pu formally slated for nuclear warheads, in an in-process condition, much of it in forms and in facilities not suited to long-term storage. The Department now faced the daunting task of eliminating the environmental, safety, and health hazards posed by this nuclear material. Such hazards include conditions or weaknesses that may lead to unnecessary or increased radiation exposure of the workers, release of nuclear materials to the environment or radiation exposure of the public. In January 1994, the Secretary of Energy instituted a Department-wide project directed by the Undersecretary for Environment, Safety, and Health to develop recommendations and to direct implementation of decisions concerning disposition of surplus fissile materials. In March 1994, the Secretary of Energy initiated the DOE Pu Environmental Safety and Healthy Vulnerability Assessment, which had the stated objective to provide a basis for safe, secure, and environmentally sound control, storage, and ultimate disposition of fissile materials.

On May 26, 1994, the Defense Nuclear Facilities Safety Board (DNSFB) [appointed by the President and the Senate of the United States and responsible for independent external oversight of all activities in DOE's nuclear weapons complex affecting nuclear health and safety] issued DNFSB Recommendation 94-1 (51, 52). This Recommendation recognized that "The halt in production of nuclear weapons and materials to be used in nuclear weapons froze the manufacturing pipeline in a state that, for safety reasons, should not be allowed to persist unremediated… that imminent hazards could arise within two to three years unless certain problems are corrected." The DNSFB recommendation was especially focused on specific liquids and solids containing fissile materials and other radioactive substances in spent fuel storage pools, reactor basins, reprocessing canyons, processing lines, and various buildings once used for processing and weapons manufacture. In essence, Recommendation 94-1 states that on a high-priority basis, a program plan must be formulated to convert high-vulnerability items to forms or conditions suitable for safe interim storage within two or three years. And within a reasonable period of time (such as eight years), all storage of metal and oxide will be in conformance with the DOE criteria for the safe storage of Pu metal and oxides (DOE-STD-3013-94, 12/94).

In the report "Plutonium: The first 50 years" DOE (5) disclosed that 3,919 kg of Pu had been diverted to waste. Of this, 919 kg are in high level waste at Savannah River, Hanford, and the INNEEL and about 3 tonnes are in low level waste. It is anticipated that most of the 3 tonnes of Pu contained in low level waste will eventually be transferred to the WIPP site in New Mexico.

In addition, the Materials Management Plan for Plutonium-239, December 1, 1998 revision, states that "approximately 3 metric tons of Pu residues, primarily at RFETS, are destine for disposal at WIPP. At RFETS, in most cases, this involves stabilization, where required, followed by blending and packaging to meet WIPP disposal and safeguards termination requirements."

ROCKY FLATS

The Rocky Flats Environmental Assessment (53) states clearly that the intent is to place residues in a condition allowing for safe interim (up to 20 years) storage irrespective of the disposition method selected in the future. The first record of decision (54) stated up to approximately 351 kg of Pu will be processed at the Rocky Flats site and packaged in preparation for disposal at the Waste Isolation Pilot Plant (WIPP) in New Mexico. The second Record of Decision (55) stated up to approximately 1,970 kg of Plutonium will be processed at Rocky Flats and packaged in preparation for disposal in the waste Isolation Pilot Plant." It went on to state: "Most, and probably all, of the remaining direct oxide reduction (DOR) salt residues containing up to about 139 kg of plutonium) will be pyro-oxidixzed (if necessary) at Rocky Flats and repackaged in a manner that ensures that no package contains more than 10 percent plutonium, in preparation for disposal in WIPP. In an amendment (56,) to the Second Record of Decision, DOE stated: "The Department of Energy (DOE) has decided to revise the approach to be used to dispose of sand, slag and crucible plutonium residues (containing approximately 130 kg of plutonium) that is currently stored at the Rocky Flats Environmental Technology Site. With the opening of the Waste Isolation Pilot Plant (WIPP) in New Mexico on March 26, 1999, DOE has now decided instead to prepare the sand, slag and crucible residues for direct shipment to the repository for disposal.

A January 6, 2000 memo from Deputy Assistant Secretary for Office of Site Closure (57) requested that Rocky Flats "suspend work on the baseline plan preparations to ship plutonium fluorides from Rocky Flats to the Savannah River Site (SRS) for stabilization. The current baseline does not appear to allow for shipment of the fluorides offsite in time to meet our closure schedule or the 94-1 milestone to ship fluorides by September 2000." How DOE/EM will resolve this with the congressional language in H. R. 2605 "Appropriations for Energy and Water Development for FY2000 Sec. 315" which states "*None of the funds may be used to dispose of transuranic waste in excess of 20 percent plutonium by weight for the aggregate of any material category"* is unexplained. The total Pu fluoride residue mass is 315.4 kg with a Pu content of 141.5 kg or 44.9 wt %.

The assumption that only 2,000 kg of Pu from all sites would be disposed of at WIPP has now been eclipsed by decisions that send about 2730 kg of Pu to WIPP from Rocky Flats alone.

HANFORD

In the "Integrated Project Management Plan for the Plutonium finishing Plant Stabilization and deactivation Project" (58) the overall goal is stated to be to "dramatically accelerate stabilization and transition and substantially reduce the project life cycle cost." This report states that "plutonium-bearing materials having less than 30 weight percent plutonium will generally be pretreated as necessary, immobilized by cementation, packaged, and removed from PFP for storage at a permitted Hanford location until eventual disposal in WIPP. At a minimum, this will send 200 kg of Pu from Hanford to WIPP. Depending upon the actual outcome of Pu solution processing, this could be as high as 400 kg of Pu.

EM OBJECTIVES FOR SURPLUS ^{239}PU

From an EM viewpoint there are 7 objectives for the Pu Disposition Program:

- Stabilize the "at-risk" material to meet 94-1 Program requirements and schedule.
- By 2002, have all materials packaged in forms and containers approved for safe interim storage.
- Consolidate materials to enable shutdown of Rocky Flats and Hanford and other sites as appropriate.

- Meet National Non-Proliferation objectives by converting surplus Pu into forms suitable for repository disposal.
- Ensure that adequate end states exist for disposal of surplus Pu.
- Meet National Security requirements and other potential programmatic and research needs for Pu.
- Provide needed infrastructure to enable accomplishment of above-mentioned objectives.

The net result of EM decisions is that approximately 3.1 tonne of Pu, instead of the anticipated 2.0 tonnes, will be sent to WIPP. In addition, 0.6 tonne of Pu still resides in Pu production targets and will be disposed of as spent fuel. Therefore EM will be disposed as waste approximately 3.7 to 4.0 tonnes of weapon-grade Pu. This is approximately 10% of the 38.2 tonnes of weapons grade Pu declared as excess to national defense needs.

EXCESS PLUTONIUM FROM A NE VIEWPOINT

O**n** August 18, 1999, Secretary of Energy Bill Richardson (59) announced that DOE would conduct a National Environmental Policy Act (NEPA) review of the environmental impacts associated with the FFTF, the next step in determining the future of the reactor. This resulted in the removal of 711 kg of Pu that had previously been prepared either as full assemblies or as individual fuel rods but not yet assembled into fuel assemblies.

In a memo from William D. Magwood (60) to Laura S. H. Holgate, NE "concluded that it is appropriate to retain the ZPPR fuel and facility in a standby condition." This, in effect, withdraws approximately 3.5 tonnes of non-weapons grade Pu from the surplus list.

The total amount of Pu removed from the non-weapons grade surplus list is about 4.2 tonnes.

OTHERS

A variety of programs are assuming the use of Pu that has been declared excess to national defense needs. If funded, it is uncertain how much Pu would be removed from the disposition feedstock. It is assumed that approximately 2 to 3 tonnes of Pu will be necessary for these programs. There have been a number of internal swaps of material. Whereas this may not affect the final total mass of Pu, it does change the mix of materials that would be feedstock to the Immobilization facility.

U. S. EXCESS PLUTONIUM FROM A RUSSIAN VIEWPOINT

The Russians have indicated that they have no interest in the amounts of Pu having ^{240}Pu concentrations higher than weapons grade (see Table 3). They also have no interest in what the United Sates is declaring waste and disposing of as waste in WIPP or as spent fuel in the national repository (see Table 3). As a result, in negotiations so far, the Russians have indicated that they will give credit to and match only 34.5 tonnes of the U. S. declared excess Pu. The Russians have recently agreed to immobilize about one tonnes of Pu.

U. S. SURPLUS PLUTONIUM AVAILABLE FOR DISPOSITION (START I ASSUMPTIONS)

As shown in Table 3, the U. S. at the end of START I actually have about 37 tonnes of Pu available to be dispositioned via the spent fuel standard. This is about 34.5 tonnes of weapons grade Pu and about 2.5 tonnes of non-weapons grade Pu.

In a speech before the Institute of Nuclear Materials Management, Laura S. H. Holgate (21) noted that "The Presidents" summit statement called for the disposition of 50 metric tons of plutonium in stages. The agreement will cover the first 34 metric tons of weapons grade Pu from weapons programs. This is the total amount of excess weapons-grade Pu the U. S. has available for inclusion in this agreement. Should additional material be declared excess by either side, the agreement will call for its inclusion either in this agreement or is some other agreement providing for similar transparency and disposition.

Table 3. Actual Disposition Plutonium Feed Stock (Tonnes Pu)

Location	Excess Weapons grade holdings	Surplus Non-weapons grade holdings	Dispose of as Waste	Spent Fuel Disposition	Retain for non-weapons use	Disposition via spent fuel standard
Pantex/future dismantlements	21.3					21.3
Rocky Flats	11.7		2.73			9.0
Hanford Site	1.7	9.2	0.2 to 0.4	6.5	0.7	3.3 to 3.5
Los Alamos	1.5	0.3	0.2	< 0.1		1.5
Savannah River	1.3	0.5	0.1	0.2		1.5
INEL	0.2	4.1		0.7	3.6	
Other Sites	0.1	0.2		0.1		0.2
Total	38.2	14.3	3.1 to 3.3	7.5	4.3	36.8 to 37.0

Note: Totals may not add up due to rounding to the nearest tenth of a tonne

SUMMATION OF CHANGES TO FEED STOCK

The original planning bases for the Disposition Program was 33 tonnes of Pu metal to MOX. If START III results in additional Pu being declared excess to national needs, then MOX may well get 33 tonnes of Pu. However, for Immobilization to have 17 tonnes of feed, a number of DOE decisions will have to be reversed. These include:

1) ZPPR fuel: 3.5 tones reserved as a national resource.
2) FFTF fuel: 0.7 tonnes for use as FFTF fuel

3) WIPP: Approximately 3.1 to 3.4 tones of Pu now destine for WIPP. (The original planning bases had assumed that 2.0 tonnes would be declared waste and sent to WIPP.)
4) Federal Repository: 0.6 tonnes of weapons grade Pu in irradiated fuel designated to be disposed of as spent fuel.

The present planning base is about 37 tonnes of Pu to be dispositioned; 34.5 tonnes of weapons grade and 2.5 tonnes on non-weapons grade Pu. Assuming that 26.2 tonne of this go to MOX fuel, this leaves, at a best case assumption, only 10.8 tonnes of Pu for immobilization.

CONCLUSIONS

Since the end of the Cold War, tens of tonnes of Pu have become surplus to defense needs in both the U. S. and Russia. Weapons stockpiles are declining; arms reduction negotiations are proceeding; and weapons dismantlements are continuing. All of these actions increase the stockpiles of surplus Pu. Given the current political instability and worsening economic conditions prevailing in Russia, there is a very real threat that Pu could be stolen or diverted into the hands of terrorists or non-nuclear nations. Since Pu can be readily fabricated into crude nuclear weapons for use not only against other nations but also in the U. S. against Americans, preventing the flow of Pu to countries of proliferation concern and to terrorist groups is a major objective of U. S. national security policy. The MD Program (1) is first and foremost a nonproliferation program; the U. S. nonproliferation focus is five-fold:

1) To secure nuclear materials in the former Soviet Union;
2) To assure safe, secure, long-term storage and disposition of surplus weapons-usable fissile materials;
3) To establish transparent and irreversible nuclear arms reductions;
4) To strengthen the nuclear nonproliferation regime; and
5) To control nuclear exports.

However, the Pu is not under the control of MD. Defense Program once managed essentially all nuclear materials. Now numerous DOE Programs have a nuclear materials responsibility:

1. Pu residues are under the control of the Office of Environmental Management (EM);
2. Pits and some of the clean metal are under the control of the Office of Defense Programs , and
3. Unirradiated fuels are under the control of the Office of Nuclear Energy Programs.

Each DOE Program manages nuclear materials consistent with its priorities. The Programs do not have the benefit of a long-term departmental vision that frames nuclear materials management needs, nor a roadmap that delineates their role in achieving an end state. Without a cooperate vision, DOE Offices that have control of Pu have made decisions that have a profound effect on the Pu Disposition Program.

At the end of the Cold War, excess facilities were transferred to EM for decommissioning. Many of the transferred facilities contain large amounts of nuclear materials produced by the Nuclear Weapons Complex, making EM one of the largest holders of nuclear materials in DOE. EMs missions are to:

- Stabilize/store weapons-capable nuclear materials until MD is ready to assume ownership, and
- Dispose of waste.

Major EM goals for FY2006 include:

- Remediation of 80 % of all release sites, that is, specific locations or areas where contaminants may have been released to the environment;
- Stabilization of all nuclear materials and spent nuclear fuel and completion of all preparations for their ultimate disposition; and
- Completion of all cleanup activities at some major sites, for example, Rocky Flats.

EM's strategy is to pursue aggressive deactivation so that risks and associated funding for facility surveillance and maintenance can be reduced. Consequently, decisions that would delay closure of a facility is deemed unacceptable—-it goes against the EM strategy even though that decision might much better support the nation's nonproliferation goals. Examples are decisions to ship tonnes of Pu to WIPP very much support a non-reprocessing policy and the EM strategy to reduce cost but run counter to the U. S. nonproliferation policy

Decisions made by DOE Offices other than MD have a great effect on the Disposition Program. The blend program in the PIP was assuming about 3 to 4 tonnes of tramp impurities to blend over about 17 to 18 tonnes of Pu. That has changed to about the same amount of tramp impurities to blend over 8 to 11.5 tonnes of Pu. However, should the Russian insists on blending the Pu isotopic up, this would add an additional approximately 8 tonnes of reasonably pure Pu oxide to the stream.

Now that the decision has been made to locate the three disposition facilities at the SRS, numerous groups are attempting to do contingency planning for MD. Whereas some of these unsolicited contingency plans may save money or spreads out the cost over a greater number of years, for the most part all of them run against policy and on-going negotiations.

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